Chapter 3

Reach Assessment

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Chapter 3 describes reach-based processes that typically result in bank erosion. It provides guidance on how to characterize the basic physical conditions of the channel in order to better identify potential reach-based causes. The reach-based assessment should be used in tandem with a site-based assessment, since both may be contributing to the erosion of the bank. Indeed, without working through the site-based and reach-based assessment processes described here and in Chapter 2, *Site Assessment,* selection of the most appropriate solutions (as described in Chapter 5, *Identify and Select Solutions*) will not likely occur.

A reach assessment attempts to answer the following five questions:

1. What are the basic physical conditions of the stream channel?
2. What are the natural and human-induced processes that are occurring?
3. Do these processes indicate a stable channel?
4. Do these processes indicate an unstable channel? If so, what is causing the instability?
5. How can the streambank be protected in order to achieve long-term ecological success?

This chapter is organized by first providing guidance on how to characterize the basic physical conditions of the channel (*see Figure 3-1*). With this information, reach-based processes can be identified. There are two basic categories of reach-based processes that cause bank erosion:

1. channels in equilibrium (stable), and
2. channels in disequilibrium (unstable).

For each of these categories, there is a range of processes that may occur (e.g., natural meander migration or aggradation). Reach-based causes responsible for triggering each process (e.g., downstream constriction causing aggradation) are described, in addition to bank-protection treatment considerations.

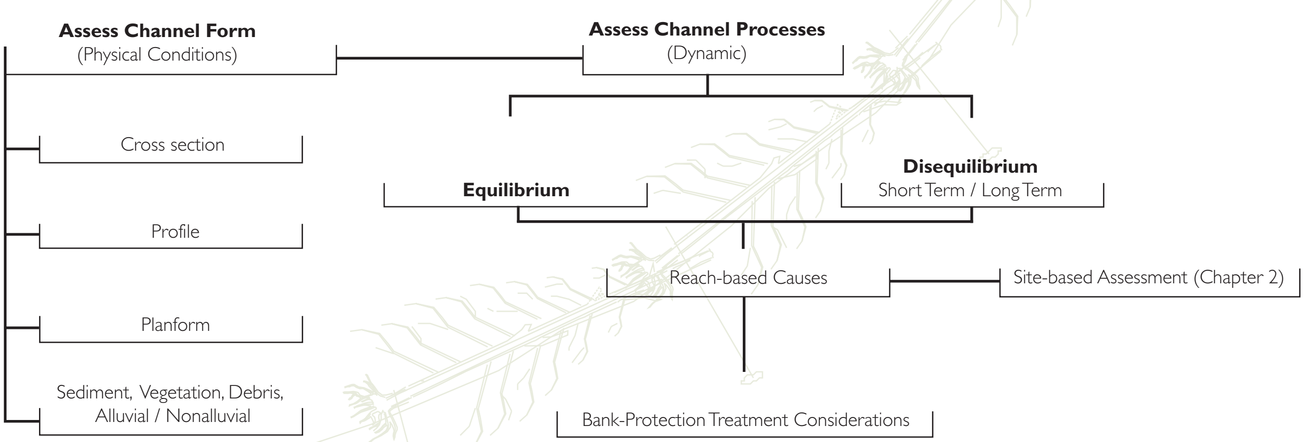

Figure 3-1. Reach-assessment approach.

CHANNEL FORM: BASIC PHYSICAL CONDITIONS OF THE CHANNEL

The basic physical conditions, or channel form, of a stream should be characterized in the initial reach assessment in order to understand the reach-based processes that are causing bank erosion. This is essential before selecting bank-protection techniques. Selecting techniques without identifying and understanding the reach-based processes can result in bank-protection techniques that fail to protect the bank and/or that trigger additional erosion.

A series of eight questions that will help characterize the physical conditions are described in *Figure 3-2*. Standard approaches to quantifying these conditions are presented in Appendix F, *Fluvial Geomorphology*.

The basic physical conditions, or channel form, of a stream should be characterized in the initial reach assessment in order to understand the reach-based processes that are causing bank erosion.

1. Is the channel alluvial or nonalluvial? Alluvial channels transport and deposit their own bank materials. As a result, they have erodible bank and bed boundaries. Nonalluvial channels have relatively nonerodible materials (e.g., bedrock or concrete), limiting erosion of the bank or bed boundaries.
2. What is the average channel slope? The channel slope represents the vertical descent of a river over a given distance, reported as percent (ft/ft) or as feet of drop per mile (ft/mile) (*Figure 3-3*).
3. What is the general sediment load? The sediment load of a stream reflects the size and quantity of sediment delivered to a given stream reach. Sediment size is commonly expressed in terms of gradations of sediment measured, where D_n equals the particle size, of which n percent is finer. For example, D_{50} refers to the particle size, of which 50 percent of the particles sizes are finer. Sediment can be measured either by weight via sieve analysis,[1] or by number via pebble count.[2] Sediment quantity is generally referred to as tons per year of sediment delivered to (transported by) a reach.
4. What is the shape and size of the channel cross section? The cross section of a channel can be expressed in terms of active width and depth, bankfull width and depth, and floodplain width (*Figure 3-4*). A useful parameter in the evaluation of channel cross section is the determination of bankfull discharge, which, in equilibrium channels, is the discharge that just fills the channel to the top of its banks and at a point where overbank flow begins.
5. What are the planform characteristics of the channel? Planform refers to the two-dimensional condition of a river as seen in map or aerial view, which is generally expressed in terms of pattern, sinuosity (channel length/valley length), and individual meander attributes such as amplitude, wavelength and radius of curvature (*Figure 3-5*). Channel planform is commonly characterized as braided (multi-channeled), meandering (sinuosity > approximately 1.5), or straight.[3] Other planform characteristics include the width of the floodplain. Channels in urban and rural watersheds are often modified by humans and have a highly altered planform.
6. What are the banks composed of? The variability in bank materials within a reach will affect bank erosion. Bank materials are often variable both horizontally and vertically.
7. What is the distribution of vegetation? The distribution, vigor and types of vegetation on the streambank can affect rates of channel change and the degree of channel stability/instability.[4]
8. What is the distribution and function of large woody debris? Large woody debris aids in the formation of pools and riffles, increases sediment storage, and creates steps in the longitudinal profile of the streambed.

Figure 3-2. Questions to ask when characterizing the physical conditions of a stream reach.

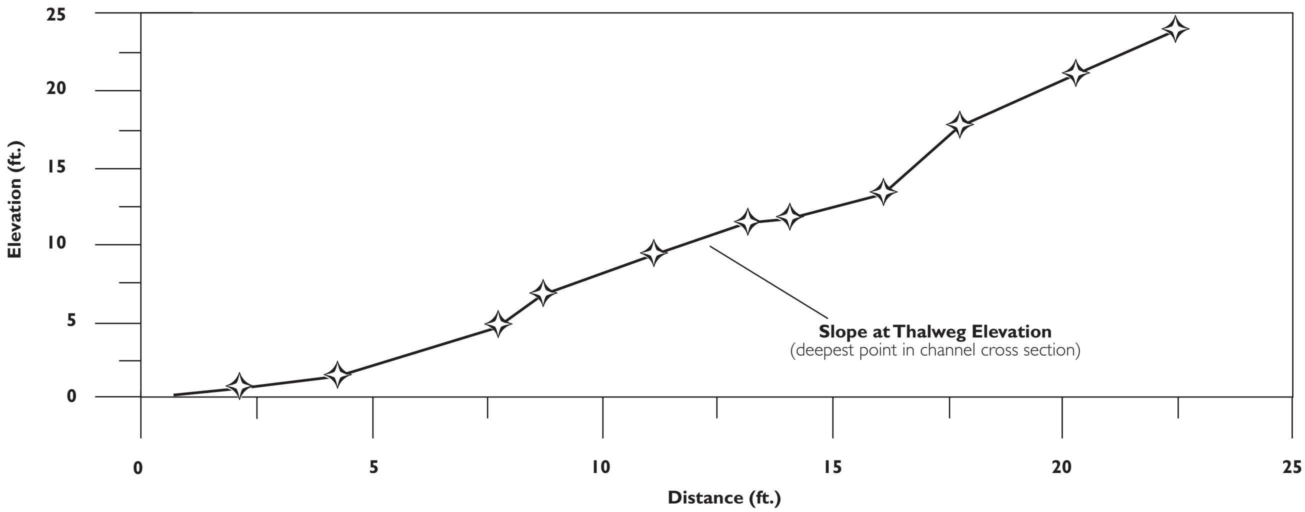

Figure 3-3. Typical channel profile.

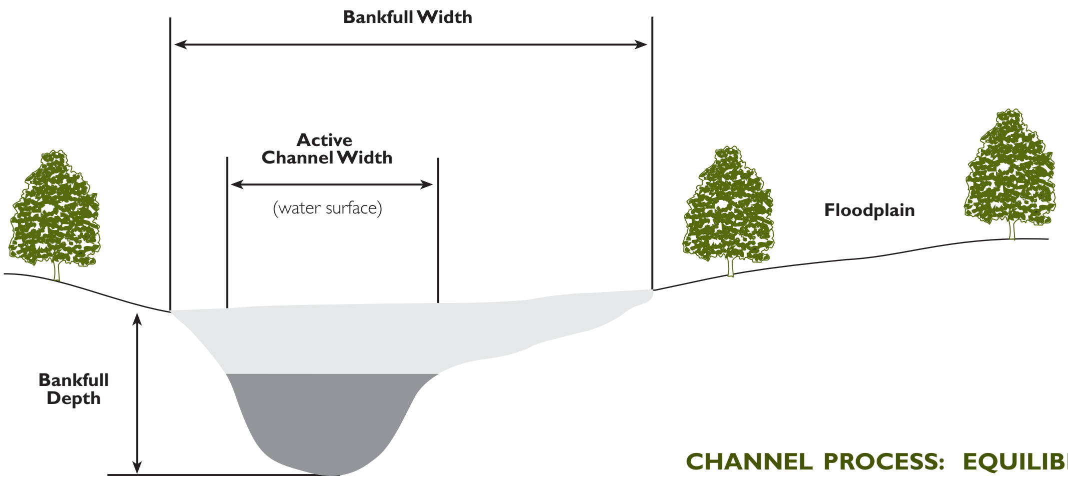

Figure 3-4. Channel cross section.

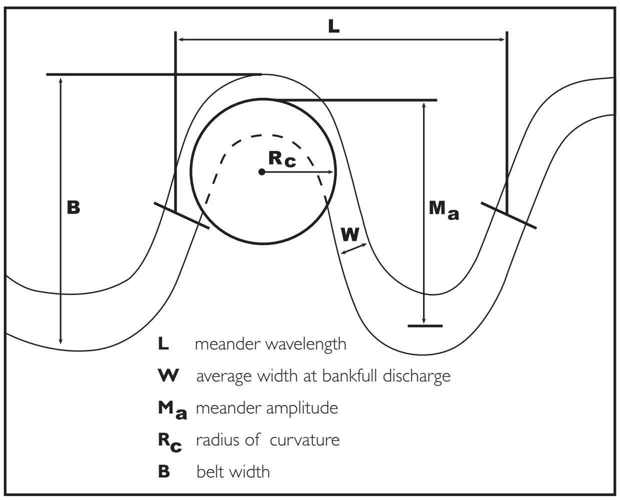

Figure 3-5. Channel planform characteristics.

CHANNEL PROCESS: EQUILIBRIUM AND DIS-EQUILIBRIUM

Collectively, channel forms describe a wide variety of channel conditions, ranging from meandering to braided. The next step in a reach assessment, then, is to determine how these components collectively reflect channel processes.

A fundamental concept in the assessment of channel process is geomorphic equilibrium (also referred to as channel stability). The concept of geomorphic equilibrium refers to a general condition of "sediment transport continuity," where the quantity and size of sediment transported into a reach is approximately equivalent to the quantity and size of sediment transported out of the reach.[5] Similarly, the sediment transport energy present within a reach is in balance with the sediment load. E.W. Lane[6] presented this concept graphically (*Figure 3-6*) as a balance scale. Tipping the scale in one direction or the other (by changing either hydrology or sediment inputs) produces an

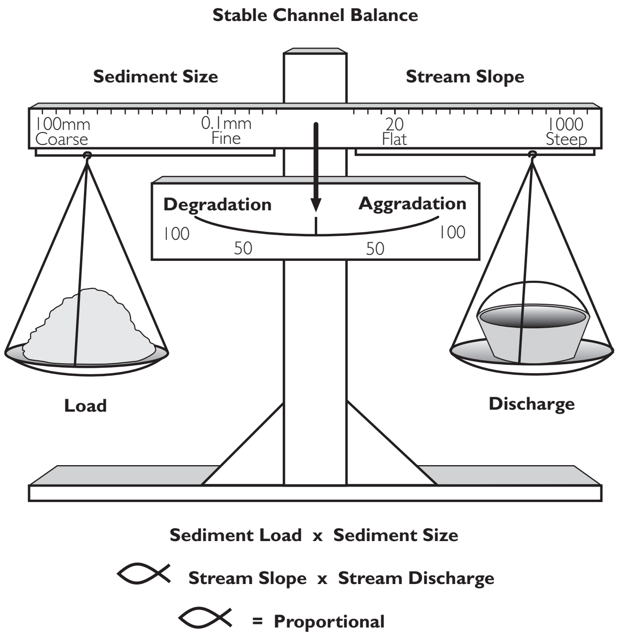

Figure 3-6. Conceptual diagram of geomorphic equilibrium.

opposing response. Geomorphic equilibrium exists when the processes of bank erosion and channel migration occur gradually. In contrast, rapid bank erosion, driven by changes in sediment load or hydrology, reflects a state of geomorphic disequilibrium, referred to as channel instability.

Identifying the reach-based causes of disequilibrium is critical in selecting long-term bank-protection solutions. The reach-based causes are summarized in *Figure 3-7*. They may indicate short-term impacts, from which the channel recovers naturally at a relatively rapid rate (such as following a flood event), or they may indicate long-term changes that will cause significant channel adjustments as part of natural recovery (for example, following dam construction or urbanization).

Geomorphic equilibrium exists when the processes of bank erosion and channel migration occur gradually. In contrast, rapid bank erosion, driven by changes in sediment load or hydrology, reflects a state of geomorphic disequilibrium, referred to as channel instability.

Table 3.1 shows mechanisms of failure and their possible reach-based causes. These relationships link the results from the site-based assessment provided in Chapter 2 to reach-based processes in this chapter. For example, the mechanism of failure called toe erosion may be triggered by site-based causes (e.g., reduced vegetative bank structure) and/or reach-based causes (meander migration, aggradation or degradation). Only by doing both a site and reach assessment can the actual cause(s) be identified.

By answering the following four questions, the reader will be able to proceed directly to the discussion on identified reach-based processes:

1. Is the channel migrating laterally? If so, at what rates? Predictable patterns of channel migration, coupled with a stable bed profile, are typical of stable alluvial channels. Accelerated migration rates or unusual erosion patterns reflect channel instability. Channel migration rates can be estimated from historic aerial photographs, channel survey data, visual observations, anecdotal information, and/or from bankline migration monitoring. Migration rates typically occur during flood events in excess of a five- to 10-year return interval. Toe erosion (see Chapter 2) is the mechanism of failure resulting from lateral channel migration.

Only by doing both a site and reach assessment can the actual cause(s) be identified.

2. Is the channel aggrading? Channel aggradation refers to the accumulation of sediment within a channel when the quantity of sediment entering a reach is more than what is leaving the reach. Aggradation is determined through repeat surveys, observations of pool in-filling, changing river pattern from single-thread to multiple-thread, widening and shallowing of channel cross section, or burial of infrastructure. Aggradation is discussed in more detail on *page 3-13.*

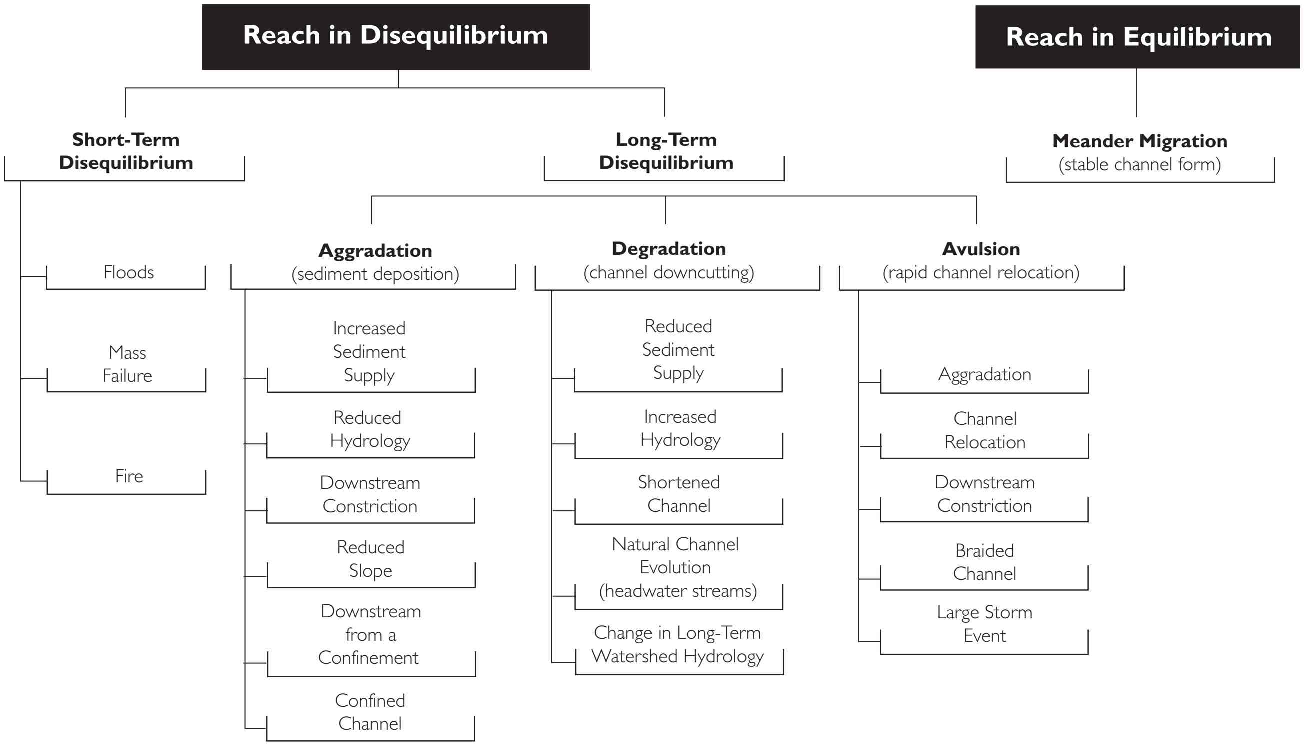

Figure 3-7. Reach-based causes of erosion.

Typical Mechanisms of Failure	Possible Reach-Based Causes
Toe erosion Neck/Chute cutoff Mass failure	Meander Migration
Toe erosion Scour: constriction jet (at a tributary) Avulsion Mass failure	Aggradation: reduced hydrology increased sediment supply confined channel downstream constriction reduced slope downstream from a confinement
Toe erosion Mass failure Drop/weir scour Subsurface entrainment	Degradation: increased hydrology reduced sediment supply shortened channel natural channel evolution change in long-term watershed hydrology

Table 3-1. Reach-based causes and associated mechanisms of failure.

3. Is the channel degrading? Channel degradation occurs when the quantity of sediment transported out of a reach exceeds what is being delivered. Degradation is recognizable through repeat surveys, observations of increased bank height (increased vertical bank exposure due to lowered channel), deepening and narrowing of channel cross section, or exposure of infrastructure foundations. Degradation is discussed in detail on *page 3-14*.

4. Has the channel avulsed? Avulsion is a rapid change in channel location and reflects channel instability in single-channeled (meandering) and multichanneled (braided) streams. Channel straightening or relocation, through constructing dikes or levees are common causes of channel avulsions. Avulsion is discussed in more detail on *page 3-16*.

For detailed information regarding geomorphic principals, methodologies for quantifying geomorphic assessment, and typical human impacts and associated physical responses of channel systems, see Appendix F.

Equilibrium Channels

Equilibrium channels are most commonly located within undeveloped watersheds, where sediment and flow inputs remain relatively constant through time. However, equilibrium can eventually be achieved even in highly urbanized settings through long-term channel adjustments to altered watershed conditions.[7] Alluvial channels in equilibrium can be identified by determining the following six questions:

1. Does the channel have a historically consistent cross section shape and size for a given channel slope and channel feature (pool or riffle)? The cross section size and shape are maintained in equilibrium channels.

2. Does the channel have a historically consistent profile and pattern? Consider the human modifications of the channel as well as the geomorphic adjustments through time.

3. Does the channel have access to its floodplain, such that over-bank flows occur during floods to dissipate excessive flow energy? Alluvial channels that are in equilibrium will have access to the floodplain during high flow events.

4. Are there predictable channel patterns, such as pool/riffle sequences in phase with the general channel planform? Meandering channels in equilibrium display features related to the channel planform (e.g., point bars on the inside and pools on the outside of bends and riffles at crossings).

5. Does the channel geometry satisfy established empirical regression equations developed for similar streams? Regression equations compare morphological relationships in stable-to-potentially-unstable channels[8, 9] (see Appendix F). These empirical equations reflect channel conditions such as slope, vegetative vigor or sediment gradations. Their application should be made cautiously, such that equations applied are appropriate for the channel.

6. Is there an absence of indicators that the channel is in disequilibrium? Field indicators of channel disequilibrium are discussed in subsequent sections of this chapter (*see page 3-11*).

One of the greatest concerns that arise when bank erosion occurs in equilibrium streams is that the stream will naturally meander into a migration corridor that contains man-made infrastructure or agricultural lands. In such cases, it may be tempting to use rigid bank-protection techniques in order to protect the property at risk. However, such an action will modify the stream's natural corridor configuration and may alter meander migration dynamics to the detriment of other properties (as discussed in the following section).

Meander Migration: Meander migration occurs in equilibrium channels. It occurs as water flows through a channel and develops spiraling flow patterns (see Chapter 2). These spiraling flows cause bank erosion along the outer bank (bend scour) and deposition on the inner bank. As a result, meander migration occurs as the outer bank erodes and the inner bank accumulates sediment. The rate of bank erosion is dependent upon

Meander migration occurs as the outer bank erodes and the inner bank accumulates sediment. The rate of bank erosion is dependent upon the shear resistance of the outer bank materials relative to the shear stress imposed on that bank.

the shear resistance of the outer bank materials relative to the shear stress imposed on that bank. Bank shear is a combined function of the flow magnitude and duration, as well as the shape of the bend and channel cross section (see Chapter 2 and Appendix E, *Hydraulics*).

Meander migration has three patterns (*Figure 3-8*)[10] :

- meander translation (downstream migration),
- meander extension (migration transverse to the valley axis), and
- meander rotation.

An example of downstream meander migration is shown in *figure 3-9*.

Vegetation increases bank-shear resistance. The ability of vegetation to add shear resistance and thereby reduce bank erosion rates depends upon the relationship between the bank height and vegetative rooting depth. Where banks are low and root densities are high, removing bankline vegetation will weaken the bank toe and increase erosion.[11] Bank vegetation disturbance is a common cause of increased erosion rates and meander migration.

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Figure 3-9. Downstream meander migration, Washington State.

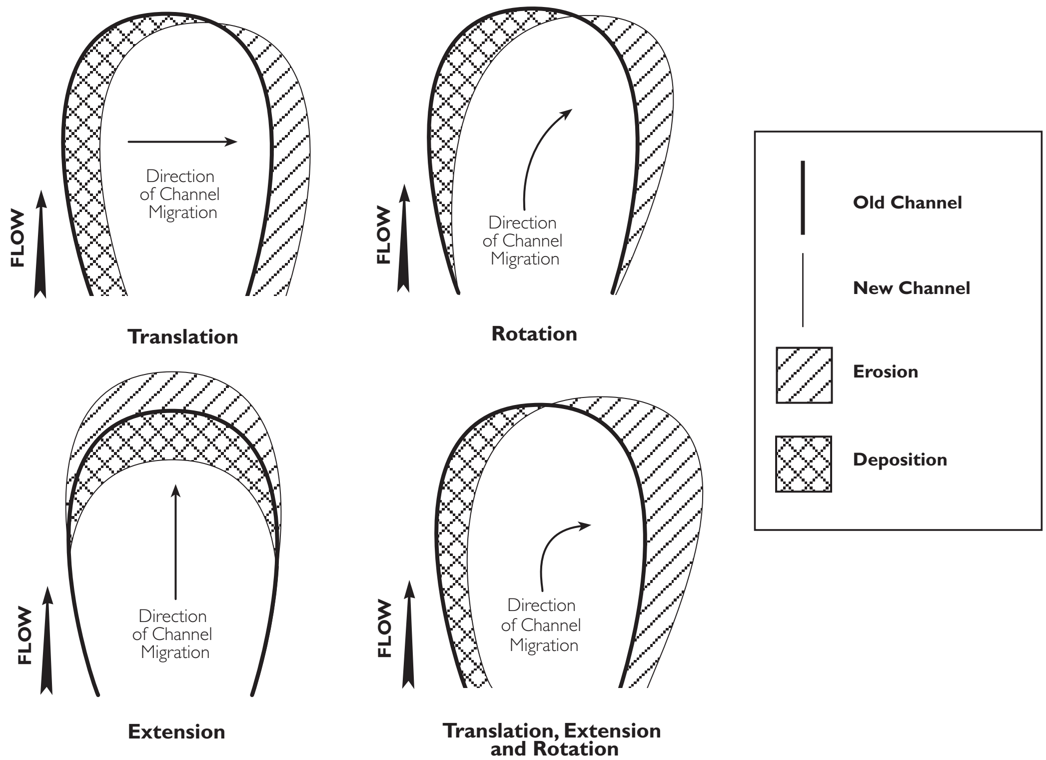

Figure 3-8. Migration patterns.

Meander Cutoffs - Chute and Neck Cutoffs:
Meander cutoffs can occur as either chute or neck cutoffs (*Figure 3-10*).[10] Neck cutoffs occur when two limbs of a bend meet due to gradual bank erosion and meander compression. Chute cutoffs occur when a bend in the stream becomes so tight that it causes sediment and debris to deposit and creates backwatered flow conditions in the upstream limb of the bend. The backwatered conditions increases the frequency of over-bank flows. As the flow shortcuts across the bar and reenters the channel on the downstream limb of the bend, erosion and the development of a new channel or "chute" results. An example of chute cutoff is shown in *figure 3-11*.

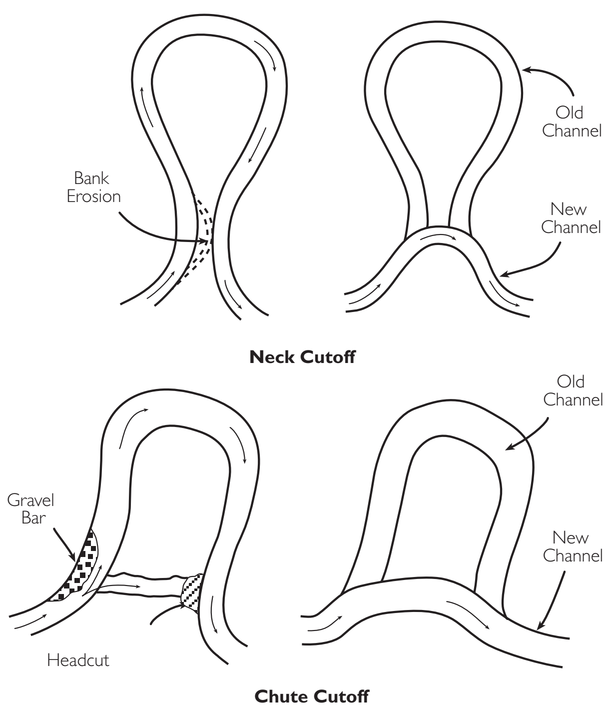

Figure 3-10. Chute and neck cutoffs.

Treatment Considerations: Channel migration and erosion patterns need to be considered during the selection of bank-protection techniques, paying careful attention to their effects on upstream and downstream channel dynamics. When short segments of migrating meanders are prevented from shifting (either by natural or artificial means), the adjacent, unprotected bankline may continue to migrate beyond the hard point, distorting the channel planform and threatening the stability and performance of the bank protection. It is critical to consider the appropriate locations and lengths of erosion control protection on a migrating meander to ensure proper performance and to prevent the exacerbation of adjacent erosion problems.

Meanders tend to migrate downstream. When a meander migrates downstream and encounters rigid bank protection (or bedrock), the meander extends across the valley, resulting in a widened migration corridor upstream.[12] The hardening of the downstream meander limb also results in meander compression, as the upstream limb continues to migrate down the valley. The meander bend will compress until it eventually cuts off and creates a new channel, resulting in rapid downcutting through the new channel for significant distances upstream. As other migrating meander bends downstream reach the same hard point, the sequence of events repeats, with successive bends extending, compressing and cutting off, as

Figure 3-11. Chute cutoff, Washington State.

shown in *Figures 3-12 and 3-13*. "Train wreck" meanders such as these (so named because the bends compress like derailed train cars) cause rapid and extensive adjustments in pattern and profile over an entire reach. In natural settings, such as at the entrance to a narrow canyon, this response results in a dynamic and unusually wide migration corridor.

Construction of rigid bank-protection techniques within the migration corridor disrupts natural meander migration and patterns of erosion. This commonly results in the need for even more bank protection, ultimately creating a rigid bankline throughout an entire reach. On alluvial channels, continuously rigid bank protection severely reduces geomorphic and habitat functions. The allowance of gradual bankline erosion and meander migration within the natural migration corridor will provide for geomorphic diversity and habitat evolution. Erosion also recruits raw substrate required for the regeneration of riparian vegetation.

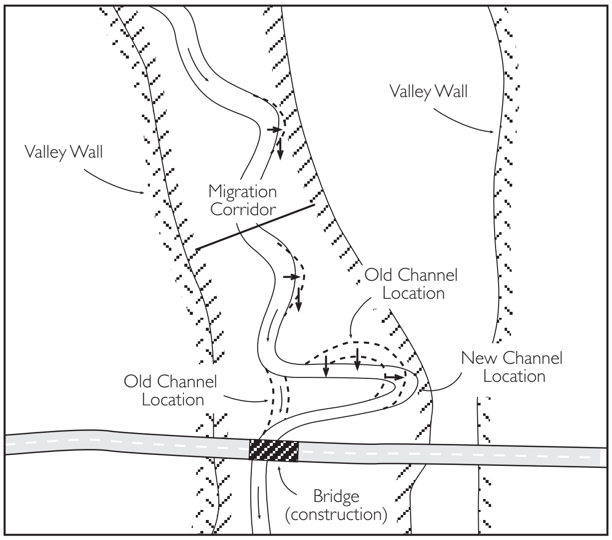

Figure 3-12. Typical meander extension and compression upstream of a constriction.

The allowance of gradual bankline erosion and meander migration within the natural migration corridor will provide for geomorphic diversity and habitat evolution.

Where gradual erosion is acceptable, but short-term, rapid erosion is not acceptable, bank-protection techniques may be appropriate if they allow eventual bank deformability (*Figure 3-14*).[13] One such technique uses degradable, erosion-control fabric wrapped around a gravel toe, overlain by a sloped, planted upper bank (see Chapter 6, *Techniques,* called *Soil Reinforcement*). It is designed to provide stability during a range of flow events, allowing upper-bank vegetation to become established prior to fabric degradation. The selection and design of these techniques are described in more detail in Chapter 5.

Where gradual erosion is acceptable, but short-term, rapid erosion is not acceptable, bank-protection techniques may be appropriate if they allow eventual bank deformability.

Nondeformable techniques, such as buried groins or rock toes, are best used along or near the edge of (and parallel to) the migration corridor to allow for natural channel migration and associated habitat evolution (*Figure 3-14*).[14] Channel stabilization along or near the edge of the migration corridor is less vulnerable to flanking and failure than similar treatments applied within the corridor. The migration corridor concept can be applied proactively, such that acceptable migration limits can be defined before addressing specific erosion threats.

Disequilibrium Channels

All streams are subjected to periodic changes. Shifts in contributing factors such hydrology, sediment load, valley slope or riparian vegetation collectively control channel morphology. However, changes do not necessarily result in channel disequilibrium. The tendency for a channel to be in disequilibrium depends upon the magnitude of a natural- or human-caused disturbance relative to the resilience of the channel. If conditions are such that the channel is just barely able to stay in its equilibrium state, a sudden change could be the last straw to throw it into

Figure 3-13. Meander extension and compression, Teanaway River, Washington State.

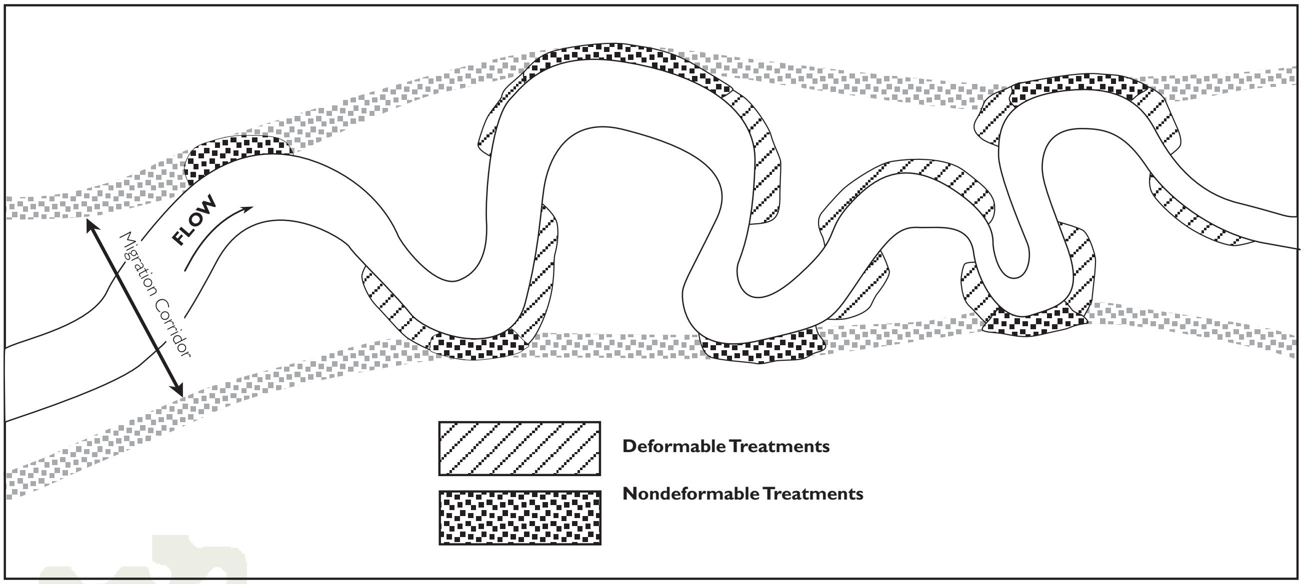

Figure 3-14. Conceptual application of deformable/nondeformable treatments across a migration corridor.

disequilibrium. If conditions are such that the channel is well within its equilibrium range, it will be more resilient, more able to accommodate a sudden change without dramatic shifts in channel shape and dimensions. (See Appendix F). For example, a slight increase in sediment load on a meandering stream that is approaching its geomorphic threshold may be all it takes to force the stream into a braided condition.[15] Such a system is prone to disequilibrium. In contrast, a stream that is already naturally braided is more resilient; its more dynamic condition enables it to accommodate and adjust to constant disturbances without requiring dramatic shifts in channel shape or dimension. Appendix F provides detailed information on disequilibrium channels.

With respect to geomorphic disequilibrium, sediment supply and hydrology must also be considered (*see Figure 3-6*).[16] When observing what appears to be a channel adjustment, it is important to remember that such adjustments may be in response to a long-term change in sediment or hydrology or may reflect a recovery from a short-term disturbance, such as a flood event. Determining the magnitude of such disturbances (short-term or long-term) and the causes of disequilibrium (*Figure 3-7*) is essential for selecting the most appropriate bank-protection solution.

Long-Term Disequilibrium:

Where a channel is subjected to changes in hydrology and/or sediment inputs, the channel will adjust (*see Lane's diagram, Figure 3-6*). Such adjustment can result in a significant change in overall stable channel form.

A major river-management challenge is to recognize that a channel is in disequilibrium, identify the causes, and develop a strategy that will promote recovery. Where the causes of disequilibrium are identifiable, a strategy should involve the

Determining the magnitude of such disturbances (short-term or long-term) and the causes of disequilibrium is essential for selecting the most appropriate bank-protection solution.

direct treatment of those causes. For example, treatment may involve removing or redesigning instream structures (e.g., weir, culvert or dam) that disrupt the natural transport of sediment, or reconfiguring a channelized stream reach. Where the causes are untreatable, such as in an urban, harvested or agricultural watershed, the strategy may involve creating a new condition of equilibrium. In these systems, an altered hydrology and sediment load may not support native-species vegetation or habitat for fish and wildlife. The ability for native species to adapt to these changes is limited; and, when those limitations are exceeded, extraordinary amounts of restoration and continual management will be required to foster recovery of native vegetation and habitat.

Altered hydrology and/or sediment load can lead to aggradation, degradation or avulsion. These are the most common reach-based processes driving bank erosion in a disequilibrium channel. These processes are triggered by one or more causes. For example, a downstream constriction (such as an undersized bridge) may cause aggradation, or shortening a channel may cause degradation.

Figure 3-7 shows the processes and causes of long-term channel disequilibrium. What follows is a discussion of each, along with treatments to consider.

Aggradation: A reach aggrades when more sediment is transported into the reach than out of the reach. Channel aggradation may occur naturally; or it may be induced or accelerated by human activities. Where a channel is in disequilibrium due to an excessive sediment supply of sediment or reduced flow energy, deposition (aggradation) occurs.[17] Aggradation will continue until the channel evolves to accommodate changes in sediment supply and hydrology (*see Lane's diagram Figure 3-6*). Localized aggradation can also occur upstream of woody debris jams, rock outcroppings or infrastructure elements (e.g., culverts and bridges) that create backwater during high flows. *Figure 3-15* shows a severely aggraded stream.

A reach aggrades when more sediment is transported into the reach than out of the reach. Channel aggradation may occur naturally; or it may be induced or accelerated by human activities.

Figure 3-15. Aggrading Channel, East Fork Grays River, Washington State.

Identifying whether a reach is aggrading can be achieved by answering the following seven questions:

1. Has the average bed elevation increased through time? Aggradation is identified by an increase in the elevation of the channel profile.
2. Has there been a demonstrated loss of channel asymmetry and associated habitat due to pool in-filling? Aggrading channels tend to shallow and widen.
3. Has the channel capacity and bankfull discharge been reduced? Has the frequency of overbank flow increased? Aggrading channels tend to flood more frequently than stable channels.
4. Has there been an increase in meander cutoff frequency? Aggradation increases the frequency of overbank flows, which increases the chances of more frequent meander cutoffs.

Altered hydrology and/or sediment load can lead to aggradation, degradation or avulsion. These are the most common reach-based processes driving bank erosion in a disequilibrium channel.

5. Has the channel shifted from a single-thread meandering pattern to a multichanneled, braided pattern? Braided channels are characteristic of streams with high sediment loads.
6. Has the channel avulsed (changed course) due to deposition within the main channel? Do avulsions commonly occur within the reach? Avulsion, common in braided channels, also occurs in meandering channels due to aggradation (*see page 3-16*).
7. Is human activity or maintenance required to maintain the desired channel condition? Channels that require human intervention to prevent changes may be aggrading.

Reach-Based Causes: The most common reach-based causes of aggradation are:

- Increased sediment supply -
    - Upstream bank erosion, mass failures, or scour can recruit excess sediment into the channel. An upstream, degrading reach is another source of excess sediment;
    - Sand and gravel stockpiling in the active channel or floodplain is a source of excess sediment recruited during flood events; and
    - Removal of instream structures, such as dams or culverts or even collections of large woody debris, can unleash an accumulation of sediment stored behind the structures.
- Reduced hydrology from upstream flood-control structures or diversions can decrease flows and the energy needed to transport sediment.
- A decrease in channel slope corresponds to a reduction in energy to transport sediment. The flow of a stream into another body of water, or the abrupt change in slope as a steep channel emerges into a valley, creates an alluvial fan or delta.
- Localized backwater effects due to constriction points at bridges, culverts, or natural hard points (e.g., bedrock) can reduce the hydraulic energy.
- Channel confinement by dikes or berms limits or prevents overbank flood flows from depositing sediment in the alluvial floodplain, resulting in deposition of sediment in the channel.

A channel will respond to these impacts by making significant adjustments to restore sediment transport continuity. These adjustments may include channel steepening, or changing channel pattern and cross-section shape. Consequently, natural recovery often results in a significant change in channel form. Some alluvial environments are naturally aggradational, such as alluvial fans, deltas and tidal environments.[10]

Treatment Considerations: Applying bank-protection treatments will not stop aggradation, and risk of flooding along the floodplain area will continue to exist. Indeed, the risk of flooding may even increase if the bank protection fails. Bank-protection treatments may also result in other highly undesirable impacts such as:

- the burying of bank protection,
- a major channel shift,
- a change from a single-thread meandering to a braided channel, or
- the widening and shallowing of the channel cross section.

Instead, reducing the sediment load or increasing the transport capacity of the reach should be considered. This can be achieved by adjusting the channel slope and cross-section (Chapter 5). Identifying and selecting a migration corridor that extends beyond the current active channel should also be considered. Broadening the channel's migration corridor will allow aggradation and recovery to occur naturally.

Degradation: A reach degrades when energy in the channel exceeds that which is required to carry the incoming sediment load (*see Lane's diagram, Figure 3-6*). It appears as a net lowering of the bed elevation over time. It may occur as a gradual, continual lowering of the entire profile (in highly erodible materials such as a sand bed channel) or as episodic lowering and formation of steep channel segments (nickpoints or headcuts) that migrate upstream.[18] A degrading channel will follow an evolutionary sequence of down-cutting to a new stable profile, followed by widening due to the collapse of over-steepened banks. The widened channel has less flow energy, so deposition and formation of a new floodplain surface occur. This new surface is below the elevation of the pre-degraded floodplain (*Figure 3-16*) and the perched, old floodplain becomes the new terrace (see Appendix F for further discussion).

Figure 3-16. Degrading channel, Washington State.

A reach degrades when energy in the channel exceeds that which is required to carry the incoming sediment load.

A degrading reach can be identified by answering the following eight questions:

1. Is there evidence of reach-wide down-cutting and lowering of the channel profile? A continual lowering of the channel profile is the clearest indicator of channel degradation.
2. Are headcuts or nickpoints evident in the channel bed? Headcuts or nickpoints are short, steep channel segments recognized as small drops or waterfalls or abnormally over-steepened channel segments.
3. Are banks consistently over-steepened and collapsing? Degrading channels tend to result in over-steepened banks that collapse. The erosion results in overall channel widening, rather than localized erosion on the outside of bends.
4. Are channel features such as bars and riffles disappearing or becoming coarser? Degrading channels erode sediment from channel features, such as spawning riffles, until they disappear. Coarsened material that is resistant to erosion remains.
5. Has the channel become detached from its floodplain? Degradation results in the perching of the floodplain above the channel bed and water table, until the floodplain eventually becomes an abandoned terrace. Side channels also become detached from the channel, destroying fish passage to side channels.
6. Has there been a loss of root penetration in the banks? Lowering of the groundwater table below the root zone will impair the survival of vegetation and reduce vegetative bank structure.
7. Have there been activities that would result in degradation? Activities such as upstream channelization or dam construction are common causes of degradation.
8. Has the hydrology of the watershed changed? An increase in impervious area (such as paved lots) and changes to the natural drainage system alter the peak and duration of flows.

Reach-Based Causes: Causes of channel degradation are shown in *Figure 3-7* and are related to either a reduction in sediment supply or an increase in hydrology. The most common causes of degradation are:

- Reduced sediment supply -
    - Sediment trapped behind instream structures, such as dams or culverts, limits the sediment transported downstream;
    - Upstream sand and gravel removal will limit sediment transported downstream;
    - Hard bank protection upstream restricts the natural recruitment of sediment; and
    - Capping floodplain sediment sources by impervious surfaces prevents the natural recruitment of sediment during flood events.
- Increased hydrology from land use changes such as past flood hazard management efforts, urbanization, agriculture and forest practices cause both an increase in peak flows and frequency and a decrease in runoff duration.[19] Changes in long-term watershed hydrology (magnitude and duration) from climatic and/or geologic events may also cause an increased hydrology.
- A channel that has been artificially shortened and straightened will have excess energy, since planform roughness has been eliminated and length has been shortened, which steepens the grade. A channel in this condition will attempt to regain a natural pattern (e.g., increase length and decrease slope) through erosion of the banks and bed.[19] Channels that are shortened and/or straightened are often confined using berms or levees, which inhibit meander migration and disconnect the channel from the floodplain. Energy is not dissipated out of the channel, because flows do not spread out across the floodplain.

- Natural disturbances operating at varying time scales are part of the sequence of natural channel evolution, where the channel changes gradually over time, leading to increased flow energy, and subsequent channel degradation. Natural causes of degradation may be related to stream and valley geology (e.g., uplift or faulting), geomorphology (e.g., lowering of base level or increased gradient), climatic change (e.g., a wetter period), and hydrologic change (e.g., increase in peak flows).[20]

Treatment Considerations: The primary concern to be aware of if applying bank-protection treatments in a degrading channel is the potential for the river to undermine the treatment by lowering its channel bed. Consequently, the design of a bank-protection technique applied at the toe of a bank must be sufficient to withstand down-cutting. This resistance is critical to project performance (in addition to depth of scour calculations based on existing conditions). Instead of using bank-protection treatments, consider using grade-control structures, which can stabilize the bed elevation. Also consider reducing the hydrology and increasing sediment storage by adjusting the channel size and shape. The size and shape of the channel can be adjusted by recreating meanders within the reach or by modifying the cross section and constructing a floodplain surface that will dissipate flow energy during flood events. Another treatment to consider is placement of large woody debris which provides storage of sediment by creating a low-velocity zone downstream for sediment to settle out and stabilize.

Avulsion: An avulsion is a significant and abrupt relocation of a new channel. (*Figure 3-17*). Avulsions are caused by concentrated overland flow, headcutting and/or scouring a new channel in the floodplain, leading to a major channel change. Avulsions typically occur in braided or aggrading channels.[12] Avulsions are different from chute or neck cutoffs in that they are not related to the predictable patterns of meander migration. Rather, they result from random channel events that vary dramatically in length and point of occurrence.

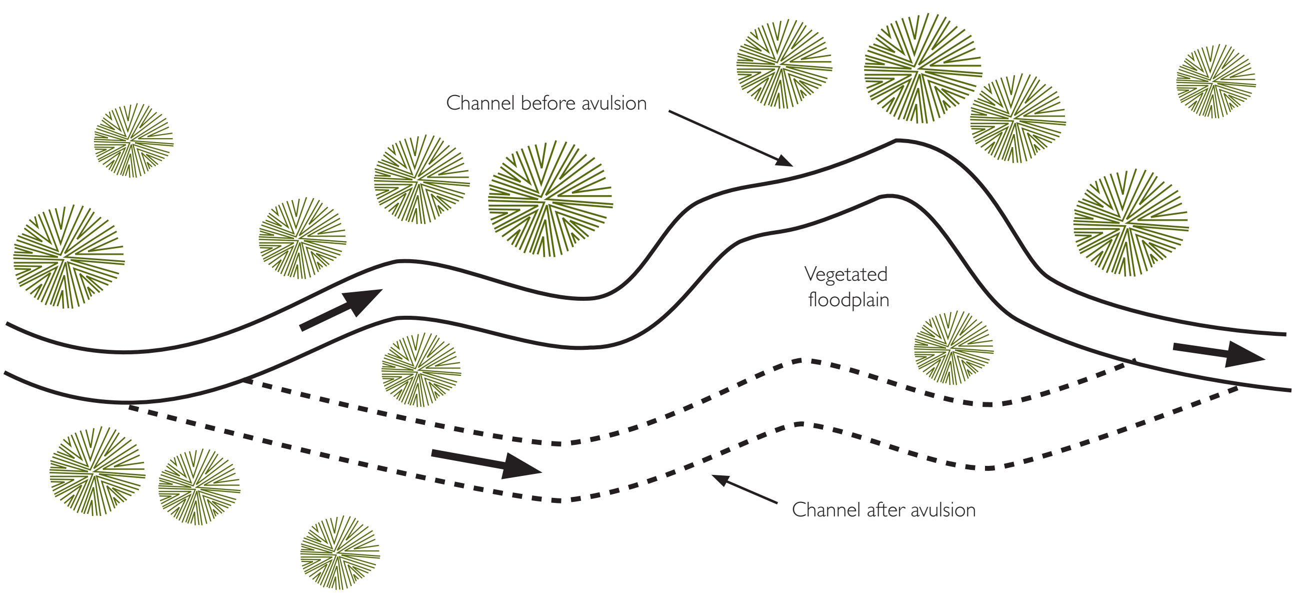

Figure 3-17. Avulsion.

An avulsion is a significant and abrupt relocation of a new channel. Avulsions are caused by concentrated overland flow, headcutting and/or scouring a new channel in the floodplain, leading to a major channel change.

An avulsion takes place sequentially as surface erosion in the floodplain progresses from small channels (rills) to gullies, to eventually cutting a new channel. After an avulsion, erosion progresses upstream in the new channel (as headcutting) and/or downstream. An obvious indicator of a potential avulsion is a nick point or headcut downstream from where the stream flowed over its banks and onto the floodplain. *Figure 3-18* shows a newly formed avulsion.

Figure 3-18. Avulsion, Quillayute River, Washington State.

An avulsion can be identified by answering the following questions:

1. Has a new channel formed over the old floodplain surface? Is it lengthening in the upstream direction and does it have a headcut on its upstream end? This reflects the fundamental process of avulsion.
2. Have large flood events recently occurred? Has the hydrologic regime changed such that the frequency of large runoff events has increased? An avulsion typically occurs during large storm events where overland flows erode the floodplain. Large storm events are extreme events that are unlikely to recur in the foreseeable future. However, in watersheds that have had their natural hydrology altered, more frequent, milder storm events may cause flooding and erosion similar to a large storm event. Hydrology is commonly altered by watershed activities (e.g., urbanization, forest and agricultural practices, and past flood-hazard management efforts) that directly change the natural hydrologic response.
3. Is the floodplain extensively eroded? The onset of the avulsion process includes the progressive erosion of the floodplain and formation of a new channel.
4. Has the main channel aggraded? A common cause of an avulsion is reduction of conveyance in a channel due to aggradation, resulting in more frequent over-bank flows.
5. Has the channel been relocated? If the channel has been relocated, the channel may avulse back to its original location.
6. Are abandoned channels common on the floodplain? Walk the site and review aerial photos. If there is evidence of abandoned channels, this reach may have historically or recently avulsed. If there are a series of scroll-shaped channels parallel to a newly formed channel, it is more likely meander migration and not an avulsion.
7. Has the floodplain been cleared of all vegetation or mined? Avulsions may occur where floodplain roughness, naturally provided by the riparian corridor, has been cleared. Also, sand and gravel mining activities are depressions in the floodplain, increasing the risk of an avulsion.

Reach-Based Causes: Reach-based causes of an avulsion are shown in *Figure 3-7* and are related to either aggradation in a meandering or braided channel or relocation of a channel from its natural location. Floodplain activity (e.g., removal of vegetation on the floodplain or in the riparian buffer) were discussed in Chapter 2 as a site-based cause of an avulsion (*see page 2-14*). An aggrading reach may result in an avulsion if the bed and water surface elevations increase the frequency of overbank flow across the floodplain. Avulsions are a common occurrence in naturally braided channels. *See page 3-13* for more information about aggradation.

Historically, many channels have been relocated due to land-use activities such as agriculture or infrastructure development. These channels were often relocated to the edge or outside of their migration corridor. In areas where this has happened, an avulsion is possible as a relocated channel attempts to reclaim its historic location within the migration corridor.

Treatment Considerations: As long as large storm events occur, avulsions will also occur. After large storm events, the human response is often to "fix" the avulsion problem (e.g., put the channel in its pre-avulsion location and armor the bank) to withstand the next large event. These "fixes" are often structural and are designed to withstand these few large events; but, more often than not, they unintentionally exacerbate bank erosion along downstream and upstream properties.

Treatment of avulsed channels is most effective if the root cause, rather than the secondary cause, is addressed. For example, if the root cause is aggradation, and the secondary cause is floodplain activities, selecting techniques that correct the root cause will most effectively reduce the avulsion risk.

The formation of backwatered, off-channel habitat within the abandoned channel increases habitat value within a reach. These abandoned channels provide winter and spring flood refuge for fish and cool, spring inflow conditions during low summer flows. Loss of these habitats is common in developed watersheds. Maintaining or fostering vegetative recovery of avulsed channels should always be considered following such an event.

Short-Term Disequilibrium:

Short-term, catastrophic impacts including floods, rapid mass failures and fires drive rapid channel change and are a fundamental component of stream dynamics. Channels affected by such events require a period of time to recover and return to geomorphic equilibrium. The recovered channel may or may not resemble the pre-impact channel. Short-term instability is valuable to fish habitat and riparian vegetation, both of which have evolved and adapted to natural channel disturbances.[21,22]

Short-term, catastrophic impacts including floods, rapid mass failures and fires drive rapid channel change and are a fundamental component of stream dynamics.

Large Flood Events: The geomorphic impact of large flood events depends on the magnitude and frequency of the events and how the channel recovers between floods.[23,24] The significance of floods in terms of channel morphology is related to climate, lithology, vegetation and the timing of the events; and their impacts vary dramatically, depending upon the geomorphic setting. For example, in semi-arid settings of sparse vegetation and thunderstorm-driven flooding (e.g., eastern Washington), channel recovery is slow, and floods commonly dominate channel form. In contrast, channels in more temperate environments (e.g., western Washington) tend to recover rapidly from flood impacts.

Floods can cause rapid changes in channel form, such as changing a single-thread, meandering channel into a braided channel, especially if a meandering channel is nearing its geomorphic threshold (Appendix F). Other effects of floods include channel widening and deepening, avulsion and extensive transport and rearrangement of sediment and woody debris.

Channels generally undergo a period of recovery following flood events. Sediment deposition and vegetative regeneration will narrow over-widened channels. Floods benefit riparian regeneration due to deposition of new substrate along the bank and in the floodplain, and a number of plant species have evolved to respond to these conditions.

Mass Failure: Rapid, mass failures from hill slopes into stream channels, including rockfalls, landslides, debris flows and slumps, can significantly alter channel dynamics.[25] Mass failures cause large plugs of sediment to enter stream channels, which can degrade fish spawning substrate and habitat.[21] The ability of the channel to transport excess sediment from hill-slope failure depends upon the size of the sediment and the energy of the stream. Increased sediment supply generally results in an altered channel slope and, potentially, a shift from a meandering to a braided channel. Mass failure events that dam a channel (either with sediment or vegetative debris) can have major downstream impacts on channel morphology if a flood spills over the top of the dam.[26] For a more detailed description of how and why mass failure occurs, review Chapter 2.

Once the excess sediment erodes, the channel will readjust to background sediment loads. However, if the excess sediment is too coarse to be mobilized, evidence of the mass failure will remain as a steep, coarse channel reach. This appears as rapids on large river systems. Mass failure contributions of large amounts of woody debris to a channel will be routed downstream and, with time, serve as valuable aquatic habitat. Some debris, however, will remain, providing stability to the bank and bed of the channel.[27, 28]

Fire: The destruction of large amounts of hill-slope vegetation by wildfire impacts stream channels by increasing runoff and soil erosion, especially in steep drainage basins,[29] mass wasting on hill slopes (through the loss of vegetation root strength,[25] and sediment deposition in the stream channel. The increased sediment load consists primarily of fine-grained soils that may degrade habitat function for many years, causing channel disturbance from stream reaches all the way up to entire drainage.[30]

Treatment Considerations: Channel restoration within areas that are damaged by short-term impacts often focus on restoring the original channel condition. In many cases, these efforts simply accelerate the natural recovery process and may, therefore, not even be necessary to achieving channel stability. Indeed, a "no action" option may be optimal if the predicted extent and time frame of recovery are acceptable. Additionally, it's important to remember that short-term disturbances such as floods create excellent aquatic and riparian habitat. Restoration efforts should be undertaken with great caution, weighing carefully the potential adverse effects on the extent, quality, or longevity of habitat created by the initial disturbance against the potential adverse effects of the proposed restoration treatment.

Where the magnitude of short-term impacts is such that a channel is likely to remain unstable for long periods of time, human interaction might be necessary. For example, where floods or mass failures result in the deposition of a new size of sediment (such as large boulders in a gravel-dominated stream), extensive channel modifications may recover channel equilibrium, to the benefit of human needs and habitat quality.

Indeed, a "no action" option may be optimal if the predicted extent and time frame of recovery are acceptable.

CONCLUSION

The variety of reach-based causes of streambank erosion makes assessment of their presence and influence challenging, but essential, in determining appropriate treatments. Evaluating reach-based causes should always occur in tandem with evaluation of mechanism of failure and site-based causes, since each can profoundly affect the other. In Chapter 4, *Considerations for a Solution* we will explore how to weave our site and reach assessments with the engineering considerations necessary to determine risk and mitigation needs for potential treatment(s).

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Figure 3-9. Source: Inter-Fluve, Inc.
Figure 3-11. Source: Inter-Fluve, Inc.
Figure 3-16. Source: Inter-Fluve, Inc.